

FIGURE 1

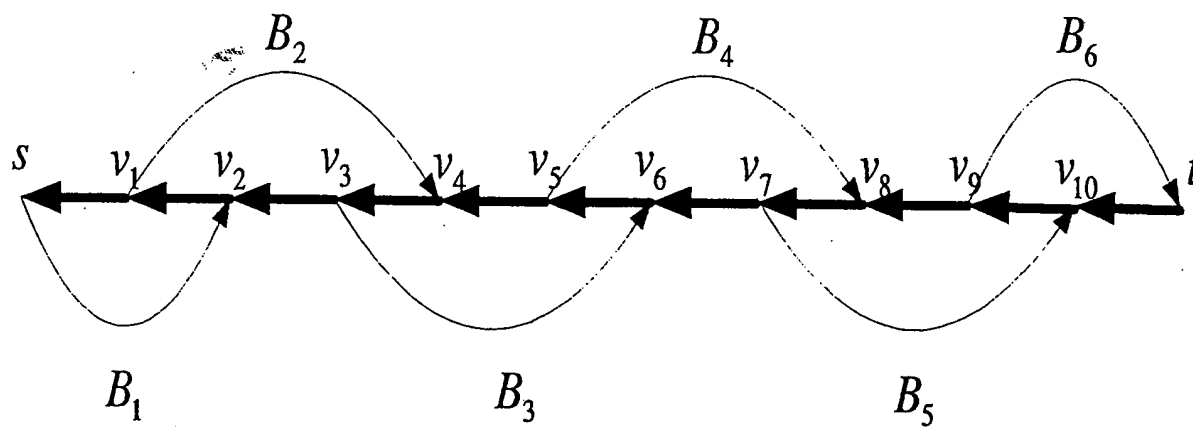


FIGURE 2

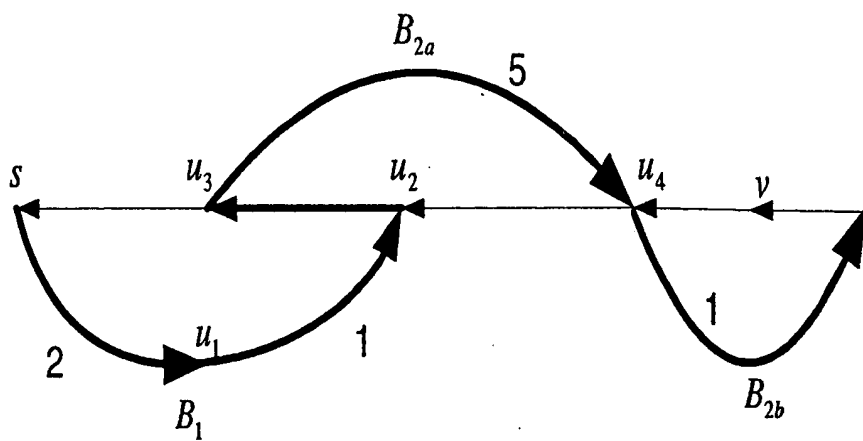


FIGURE 3

Algorithm PP ($G(V, E), \hat{\mathcal{P}}, \hat{d}, U$)

parameters:

$G(V, E)$ - network,
 $\{d_i, c_i\}_{i \in E}$ - delays and costs of the network links,
 $\hat{\mathcal{P}} = \{s = v_0, v_1, \dots, t = v_n\}$ - QoS path,
 \hat{d} - delay constraint,
 U - the upper bound on the cost of \mathcal{R} .

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1   $\Delta \leftarrow \hat{d} - D(\hat{\mathcal{P}})$ 
2   $E' \leftarrow E$ 
3  for each link  $l = (v_i, v_{i+1}) \in \hat{\mathcal{P}}$  do
4     $E' \leftarrow E' \setminus \{(v_i, v_{i+1}) \in \hat{\mathcal{P}}\}$ 
5     $E' \leftarrow E' \cup \{(v_{i+1}, v_i) \in \hat{\mathcal{P}}\}, c_{(v_{i+1}, v_i)} \leftarrow 0$ 
6  for all  $v_i \in V$  do
7     $D_{v_i}[0] \leftarrow \infty$ 
8     $D_s[0] \leftarrow 0$ 
9  for  $c = 1, 2, \dots, U$  do
10   for each  $v_j \in V$  in order such that  $v_j$  is before  $v_{j'}$  if  $v_j$  is a successor of  $v_{j'}$  in  $\hat{\mathcal{P}}$  do
11      $D_{v_j}[c] \leftarrow D_{v_j}[c - 1]$ 
12     for each link  $l = (v_i, v_j) \in E'$  do
13       RELAX( $l(v_i, v_j), c, \Delta$ )
14     if  $D_i[c] \leq D(\hat{\mathcal{P}})$  then
15       determine walk  $\mathcal{W}$  by backtracking
16       return  $\mathcal{W}$ .
17 return FAIL

```

Procedure RELAX ($l = (v_i, v_j), c, \Delta$)

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1  if  $v_j \in \hat{\mathcal{P}}$  and  $v_i \in \hat{\mathcal{P}}$  then
2    if  $D_{v_i}[c] \leq D(\hat{\mathcal{P}}_{(s, v_i)})$  then
3       $D_{v_j}[c] \leftarrow \min\{D_{v_j}[c], D(\hat{\mathcal{P}}_{(s, v_j)})\}$ 
4  else
5    if  $c_i \leq c$  then
6       $D_{v_j}[c] \leftarrow \min\{D_{v_j}[c], D_{v_i}[c - c_i] + d_i\}$ 
7    if  $v_j \in \hat{\mathcal{P}}$  and  $D_{v_j}[c] \leq D(\hat{\mathcal{P}}_{(s, v_j)}) + \Delta$  then
8       $D_{v_j}[c] \leftarrow \min\{D_{v_j}[c], D(\hat{\mathcal{P}}_{(s, v_j)})\}$ 

```

FIGURE 4

Algorithm RT ($G(V, E), \hat{P}, \hat{d}, \epsilon$)

parameters:

$G(V, E)$ - network

$\hat{P} = \{s = v_1, v_2, \dots, t = v_n\}$ - QoS path,

\hat{d} - delay constraint

ϵ - approximation ratio

```

1   $L, U \leftarrow \text{BOUND}(G(V, E), \hat{P}, \hat{d})$ 
2  do
3     $B \leftarrow \sqrt{L \cdot U}$ 
4    if  $\text{TEST}(G(V, E), \hat{P}, \hat{d}, B, \epsilon)$  returns YES then
5       $L \leftarrow B$ 
6    else
7       $U \leftarrow 2 \cdot B$ 
8  until  $U/L \leq 8$ .
9   $\mathcal{W} \leftarrow \text{SCALE}(G(V, E), \hat{P}, \hat{d}, L, U, \epsilon)$ 
10 return the restoration topology that corresponds to  $\mathcal{W}$ .
```

Procedure $\text{SCALE}(G(V, E), \hat{P}, \hat{d}, L, U, \epsilon)$

```

1   $S \leftarrow \frac{L\epsilon}{2N}$ 
2  for each link  $l \in E$  do
3     $c'_l \leftarrow \lfloor \frac{c_l}{S} \rfloor + 1$ 
4   $\tilde{U} \leftarrow \lfloor \frac{U}{S} \rfloor + 2N$ 
5  return  $\text{PP}(G(V, E), \{d_l, c'_l\}_{l \in E}, \hat{P}, \hat{d}, \tilde{U})$ 
```

Procedure $\text{TEST}(G(V, E), \hat{P}, \hat{d}, B)$

```

1  Apply Procedure SCALE for  $(G(V, E), \hat{P}, \hat{d}, B, B, 2)$ 
2  if Algorithm SCALE returned FAIL then
3    return NO
4  else
5    return YES
```

Procedure $\text{BOUND}(G(V, E), \hat{P}, \hat{d})$

```

1  let  $c^1 < c^2 < \dots < c^r$  the distinct costs values of the
   links.
2   $low \leftarrow 1$ ;  $high \leftarrow r$ 
3  while  $low < high - 1$ 
4     $j \leftarrow \lfloor (high + low)/2 \rfloor$ 
5     $E' \leftarrow \{l \mid c_l \leq c^j\}$ 
6    set  $c_l \leftarrow 1$  for each  $l \in E'$ 
7    apply Algorithm PP on  $(G'(V, E'), \hat{P}, \hat{d}, 2N)$ 
8    if Algorithm PP returned FAIL then
9       $high \leftarrow j$ 
10   else
11      $low \leftarrow j$ 
12   $U \leftarrow 2N \cdot c^{high}$ ;  $L \leftarrow c^{high}$ ;
13  return  $L, U$ ;
```

FIGURE 5

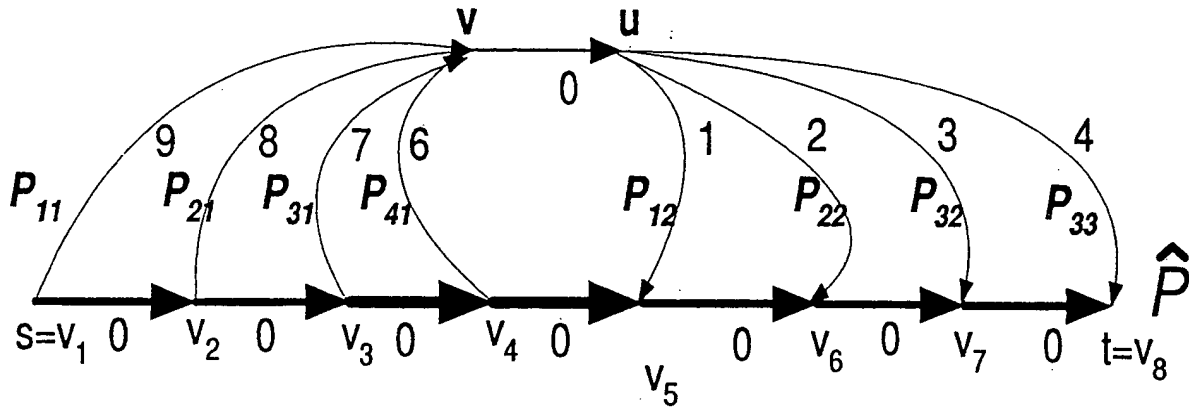


FIGURE 6

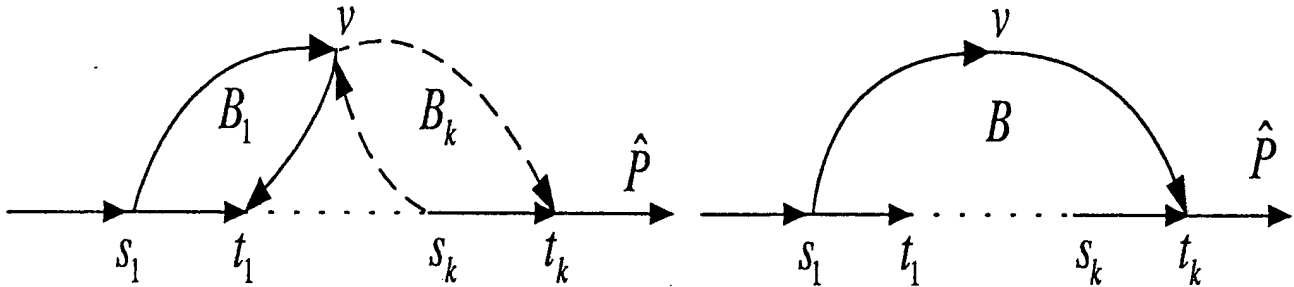


FIGURE 7

Algorithm DRT ($G(V, E), \hat{P}, \hat{d}, \epsilon$)

parameters:

$G(V, E)$ - network

$\hat{P} = \{s = v_1, v_2, \dots, t = v_n\}$ - QoS path,

\hat{d} - delay constraint

ϵ - approximation ratio

- 1 $\hat{d}' \leftarrow 2\hat{d} - D(\hat{P})$
- 2 $L, U \leftarrow \text{BOUND}(G(V, E), \hat{P}, \hat{d}')$
- 3 do
- 4 $B \leftarrow \sqrt{L \cdot U}$
- 5 Apply Procedure SCALE for $G(V, E), \hat{P}, \hat{d}', B, B, \epsilon$
- 6 if Procedure SCALE return FAIL then
- 7 $L \leftarrow B$
- 8 else
- 9 Set \mathcal{W} be the walk returned by Procedure SCALE
- 10 if $C(\mathcal{W}) \leq L$ then
- 11 return the restoration topology \mathcal{R} that corresponds to \mathcal{W} .
- 12 else
- 13 $U \leftarrow 2 \cdot B$,
- 14 until $U/L \leq 8$.
- 15 Apply Procedure SCALE for $(G(V, E), \hat{P}, \hat{d}', L, U, \epsilon)$
- 16 if Procedure SCALE does not fail then
- 17 Set \mathcal{W} be the walk returned by Procedure SCALE
- 18 return the restoration topology \mathcal{R} that corresponds to \mathcal{W} .

FIGURE 8

